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Report No. NADC-91028-60

ADAPTIVE FUNCTION ALLOCATION FOR INTELLIGENT COCKPITS

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1 JANUARY 1991

FINAL REPORT
Period Covering October 1989 to October 1991
Program Element No. 62232N
Project No. RS34H20

Approved for Public Release; Distribution is Unlimited

Prepared for
OFFICE OF NAVAL TECHNOLOGY (ONT-222)
800 N. Quincy St.
Arlington, VA 22217-5000

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Reviewed By: N G Smith Date: 29 May '91
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UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for Public Release; Distribution is Unlimited
4 PERFORMING ORGANIZATION REPORT NUMBER(S) NADC-91028-60	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Air Vehicle and Crew Systems Technology Department 6b OFFICE SYMBOL (If applicable) 6021	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) NAVAL AIR DEVELOPMENT CENTER Warminster, PA, 18974-5000	7b ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING / SPONSORING ORGANIZATION OFFICE OF NAVAL TECHNOLOGY 8b OFFICE SYMBOL (If applicable) ONT-222	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) 800 N. Quincy St. Arlington, VA 22217-5000	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO: 62232N PROJECT NO: RS34H20 TASK NO: WORK UNIT ACCESSION NO:

11 TITLE (Include Security Classification)
Adaptive Function Allocation for Intelligent Cockpits

12 PERSONAL AUTHOR(S) Jeffrey Morrison, Dr. Jonathan Gluckman, PH.D. and LCDR John Deaton, PH.D.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Final	FROM 10/89 TO 10/91	1991 January 1	

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Human Factors, Automation, Adaptive Automation, Decision Aiding, Workload

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

A series of Cockpit Automation Studies are being performed at the Naval Air Development Center (NADC) as part of the Adaptive Function Allocation for Intelligent Cockpits program. The goal of the program is to develop a prospective set of human performance based principles and guidelines for the application of adaptive automation technology. As the first study this research developed a basic set of tasks in which automation concepts could later be applied. Derivatives of two common laboratory tasks were used: one task was a pursuit tracking task while the other task was a tactical assessment task (TAT). Subject's response time and accuracy were measured on the TAT while root mean square errors (RMSE) was obtained on the tracking task. Simple and complex task performance was measured as a function of task difficulty. Three subjects participated in three 1 1/2 hour sessions. Simple task results generally supported a resource view of human performance; that is, performance decreased as tracking (over)

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Jeffrey Morrison	22b TELEPHONE (Include Area Code) (215) 441-1443 22c OFFICE SYMBOL (Code 6021

DD Form 1473, JUN 86 *Previous editions are obsolete* SECURITY CLASSIFICATION OF THIS PAGE

S/N 0102-LF-014-6603 UNCLASSIFIED

task frequency and TAT event rate increased. There was a ceiling effect for TAT accuracy which minimized the effects of TAT difficulty manipulations. Complex task performance, consistent with resource theory demonstrated poorer performance. Implications of results.for adaptive automation were given. Implications for future investigations were discussed along the lines of developing more realistic tasks and improved interface designs.

SUMMARY

A series of **Cockpit Automation Studies** are being performed at The Naval Air Development Center (NADC) as part of the ***Adaptive Function Allocation for Intelligent Cockpits*** program. The goal of the program is to develop a prospective set of human performance based principles and guidelines for the application of adaptive automation technology. These guidelines are being developed for the tactical aircraft cockpit, but may be suitable for other applications. NADC's **Cockpit Automation Studies** are a programmatic series of studies designed to take human performance theories and models found in the experimental literature, and extend them to the problems of adaptive automation. The studies will serve as the basis for developing an environment in which alternative adaptive automation concepts may be demonstrated and validated.

As the first **Cockpit Automation Study** (CAS), the baseline study served to develop a basic set of tasks in which automation concepts could later be applied. In order to assess the effects of automation on human performance, it is necessary to anticipate what the effects of automation are likely to be on human performance, so that the experiment tasks developed to study these effects will be sensitive to the anticipated effects, and diagnostic in understanding those effects. Given the many critical tasks found in an aircraft cockpit, it was determined that variations of two common laboratory tasks could be used as the starting point in this research. One task was a two-dimensional, first-order, pursuit tracking task, which is theoretically analogous to the primary flight control task performed by pilots. The second task is a derivative of the binary classification task used in much of the experimental literature examining human cognition. This "Tactical Assessment Task" (TAT) requires subjects to make a binary decision (Friendly/Hostile) to targets as they move across a screen. Responses for the TAT are made by pressing one of two buttons (Confirm/Designate) when the target reaches a range marker on the display. The subject's response time and

accuracy are measured to ascertain performance.

Various aspects of the two tasks used in this study were manipulated separately and in combination to determine how they effect performance. It was desirable that performance on each of the individual tasks be analyzed and interpreted separately as well as together so that performance trade-offs between tasks could be examined. To obtain changes in performance, the driving frequency of the tracking task was manipulated, while the number of target types and target event rate were manipulated on the TAT. All these manipulations have previously been shown to effect subject performance, and may be operationally used to manipulate task difficulty. However, the interpretation of results when such tasks are placed in combination has proven difficult, and often dependent on certain theoretical assumptions. Therefore, one of the objectives of the baseline study was to develop a methodology which would allow an interpretation of "complex" (multiple tasks, performed concurrently) task performance with a minimal of theoretical, and potentially controversial, assumptions.

Several iterations of the baseline experiment were performed as the tasks were developed. Idiosyncrasies in the operation of the tasks were corrected and task difficulty parameters were adjusted to obtain sensitive and diagnostic measures. The data collected showed that, overall, Root-Mean-Square (RMS) error collected on the tracking task and TAT response time were most sensitive to manipulation of difficulty on either the TAT or tracking tasks. TAT percent correct was found to be somewhat less diagnostic. In general, manipulations of task difficulty had the desired effect on the dependent measures, i.e. increasing the difficulty of the task and decreased performance. The data from the final iteration of the study suggests that task parameters have been found which produce results that may be explained in the context of an optimal arousal hypothesis. There is also evidence which suggests that performance tradeoffs were made in the complex task groups, and that beneficial shifts in problem solving strategies may have occurred between

simple and complex tasks.

The baseline study achieved its objectives of: 1) Developing an appropriate task environment for examining issues in adaptive automation; 2) Ensuring that the tasks would be sensitive and diagnostic to changes in human performance when component tasks, or aspects of those tasks, are in fact automated; 3) A methodology was found allowing the potentially complex tradeoffs to be interpreted; and 4) Issues and caveats for future research were identified. Based on the results of this study, a second CAS experiment is now under way at NADC and a third is being developed. Further, the task has served to elicit a number of information transfer possibilities for 6.3 programs.

ACKNOWLEDGEMENTS

We would like to extend our appreciation to a number of people who made this research possible. Michael J. Barnes of the Army Research Institute initiated the *Adaptive Function Allocation for Intelligent Cockpits* program, and has continued to provide valuable advice and insight on the program and the Cockpit Automation Studies described in this report. Dr. Raja Parasuraman of The Catholic University of America served as consultant to this program and has given us a number of valuable insights. Finally, we would like to acknowledge the efforts of Edward "Ted" Hitchcock of the Naval Air Development Center during both the document preparation and the data collection for this study.

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INTRODUCTION

The demands associated with flying modern tactical, strategic and commercial aircraft have made the cockpit a prime arena for the development of technology designed to aid human operators. The development of ever more powerful computers, expert systems, and artificial intelligence technology has led researchers and system designers to propose that decision making by aircraft pilots may be aided dynamically using this technology. The implementation of this technology may modify the tasks normally performed by pilots in any of a number of ways, in order to facilitate the best performance of the person-machine system. A number of programs are currently underway in both the military and civilian sectors designed to explore the question of what is possible with this technology, i.e. "What can be done to change the pilot(s) tasks?". This question, however, is only one of the questions that needs to be addressed before this technology is applied to the aircraft cockpit.

Perhaps a more important question is to identify the consequences and problems likely to be encountered by the pilots/users of these technologies, i.e. "What should be done to change the pilot(s) tasks given his capabilities?". The ***Adaptive Function Allocation for Intelligent Cockpits*** program, is working towards answering this question by identifying human performance based principles and guidelines for the application of adaptive automation. In support of this program, a series of **Cockpit Automation Studies** is being undertaken at NADC to generate empirical data to validate proposed guidelines. This report describes the results of the first **Cockpit Automation Study** (CAS).

Background

To understand the potential impact of adaptive automation on human performance, it is appropriate to first describe adaptive automation and how it might work. Adaptive automation differs from conventional or nonadaptive automation in

that the tasks performed by the pilot may be changed in some way by the automation system itself. The automation system may determine when and how a task is changed, alter which tasks are performed by the human and machine components of the system, it may take on certain components of tasks while others are retained by the operator, or it might alter the operating characteristics of specific tasks (Andes & Rouse, 1990; Parasuraman, Bahri, Deaton, Morrison, & Barnes, 1990).

Unlike adaptive systems, conventional automation systems may change the way the operator performs a task or tasks, but the operator makes the determination as to when the system is activated and, quite often, what form it will take. The pitfalls of this strategy are that it fails to take full advantage of the new developments in artificial intelligence and expert system technology, and that human operators are often overloaded at those times when such technology would be most advantageous. Yet it is precisely these times when human operators are least able and likely to invoke automation (Parasuraman, Bahri, Deaton, Morrison, & Barnes, 1990). Adaptive automation, however, has been advocated to overcome these shortcomings. It is proposed that the machine component of an adaptive system could take responsibility for determining when it is appropriate to assume responsibility for performing some task, or changing a task's characteristics so that it is more easily performed. The exact mechanisms which could be used to drive such a complex decision making system have yet to be clearly defined or researched. There are, however, several alternatives which have been described.

Table 1 represents a basic outline of the design strategies and philosophies applied by designers to adaptive automation systems. Each strategy reflects a general philosophy regarding what should drive the adaptive allocation algorithms: mission requirements or operator needs. Currently, designers implement decisions based upon their understanding of human capabilities, technology, and their individual design preferences. The strategies described in Table 1 include: 1) Allocation, in which well defined tasks are reallocated between the human and aiding system; 2)

Table 1. Functional Implications of Adaptive Automation Design Strategies and Philosophies

		Strategy		
		Allocation	**Partitioning**	**Transformation**
		Well defined tasks are reallocated between the operator and the aiding system.	Parts of tasks, (or subtasks) are performed by the operator while parts of the same task may be performed by the aiding system.	The aiding system restructures the operator task interaction such that the task requirements, from the operator perspective, are changed.
Philosophy	**Mission Requirements Centered**	Tasks are reallocated from operator to aiding system as a function of mission phase.	Aspects of tasks are assumed by the operator or aiding system as a function of mission phase.	Tasks are modified as a function of mission phase.
	Human Operator Centered	Tasks are reallocated from operator to aiding system based upon operator needs, preferences, and/or performance.	Aspects of tasks are assumed by the operator or aiding system based upon operator needs, preferences, and/or performance.	Tasks are modified based upon operator needs, preferences, and/or performance.

Partitioning, in which aspects of a task (or a sub-task) are performed by the human operator while other aspects of the task are performed by the aiding system (different aspects of the task may also be performed by the aid system and human operator at different times); and 3) Transformation, in which operator interaction with a task is essentially changed by the aiding system in order to change the requirements on the human operator. The particular strategy and philosophy chosen by designers for adaptive aiding systems is typically dependent on the criticality of the tasks to successful completion of the mission and, to a large degree, technology limitations. However, experience with existing aiding systems has shown that the operator's capabilities and limitations must also play a critical role in the success of the aiding system in meeting its design requirements.

The implementation of adaptive automation could have a number of impacts on pilot performance, both beneficial and detrimental, because of the changing set of tasks and performance demands with which human operators will be forced to cope as a result of adaptive automation. Before such systems can be implemented, the impact on task performance of this new technology must be fully understood (Parasuraman, Bahri, Deaton, Morrison, & Barnes, 1990).

A number of benefits have been anticipated from the development of adaptive automation systems. First, adaptive automation could alleviate some of the negative aspects of nonadaptive automation such as performance decrements associated with long term monitoring, loss of situation awareness, and manual skill degradation (Parasuraman, Bahri, Deaton, Morrison, and Barnes, 1990). This has been suggested for several reasons. An operator with an adaptively automated system would actually perform monitoring tasks some of the time. Therefore, the number and duration of periods in which they would be involved in system monitoring should be diminished, preventing decrements in performance commonly associated with vigilance. The reduced potential for a vigilance decrement should have a positive effect on overall performance. Related to this issue is the tendency of human operators to be less

aware of the "status" of a task when not actively involved in task performance. Adaptive automation could increase the operator's awareness of the task because, in fact, they would perform it some of the time. Similarly, manual control skills should be less degraded in an adaptively automated system because the operator is forced to exercise manual control whenever the system is not automated. (For a review of these issues see Hancock, Chignell, & Lowenthal, 1985; Noah & Halpin, 1986; Parasuraman & Bowers, 1987; Rouse, 1976, 1988; Wickens & Kramer, 1985).

The potential problems with adaptive automation have been pointed out by a number of human performance researchers. Weiner (1988), in his field studies of pilot problems encountered with current technology commercial aircraft, has noted that one new task that pilots will need to cope with is intervention when an automated system fails. Deficiencies during the performance of intervention could have catastrophic consequences. As noted by Logan (1990) and Gluckman (1990), the time required for operators to adjust to the dramatic changes in task load, such as those associated with automated system failure can vary greatly, and has not been completely explored. Yet, this one factor could render adaptive automation useless in many settings, including aviation, if the temporal adjustment of attention resources is sufficiently slow.

CAS-1: Baseline Study

The present paper represents the beginning of a programmatic line of research into the interactive effects of cockpit tasks on human and system performance. Since this is a relatively new area of research, a number of basic issues must be addressed regarding methodology. Therefore, some of the main objectives of this study include: 1) Providing baseline empirical data for predicting performance in future research; 2) Developing appropriate data interpretation procedures; and 3) Assessing the sensitivity and appropriateness of the dependent measures and independent manipulations. The ultimate result of this effort will be baseline data for human performance which will be used as a basis for assessing the effects of adaptive

automation in later studies. As the CAS research program matures, the data collected across studies will allow the costs and benefits of alternative adaptive automation strategies to be evaluated relative to performance without such strategies. With these data in hand, it will be possible to develop a set of human performance based guidelines and principles for the application of adaptive automation systems in the tactical aircraft environment.

In order to meet the goals of the Cockpit Automation Program, NADC's reconfigurable cockpit (RC) is being utilized as the primary research platform. This system incorporates multiple display and logic processors to control multiple independent tasks, or an integrated flight simulation. The relatively distributed processing architecture of the RC allows various tasks to be implemented at different levels of complexity and realism with minimal impact on the operation of other tasks in the scenario. In addition, the inherent flexibility of this system makes it an appropriate candidate for an evolutionary series of studies because of the degree to which the developed code for running and analyzing the tasks may be reutilized as tasks are inserted into, and removed from a common testing environment. Thus, the RC provides the ability to manipulate the specific set of tasks which are presented at any given time, thereby enabling tasks to be systematically isolated, and combined, as well as automated or released from automation. Further, and of particular importance to the study of adaptive automation, all of the mentioned changes in task parameters can be systematically made without subject or task interruption.

A preliminary analysis of the tasks performed in tactical fighter aircraft served as the basis for developing appropriate tasks for this investigation (Cohen, 1990). Tasks were chosen and developed based upon their ecological validity, (i.e. their generalizability to flight activities), the ability to operationally define levels of task difficulty, and the degree to which they could be related to standard human performance tasks found in the research literature. Two basic tasks were developed for the present study on the basis of this analysis. One task was chosen to represent

a continuous perceptual/motor task, with requirements similar to those found in controlling aircraft flight. The actual task developed was a first-order, two-dimensional, pursuit tracking task. The second task was chosen to represent a visual/cognitive task, analogous to monitoring a horizontal situation display (HSD). Thus, the Tactical Assessment Task (TAT) developed for this study required monitoring the movement of a number of targets which would then be identified by the subject as they traversed the screen. Both the tracking and TAT tasks have well documented analogs in the human performance literature (Briggs & Blaha, 1969; Briggs & Johnsen 1973; Briggs & Shinar, 1972; Poulton, 1974; Sternberg, 1967; Wickens, 1984;). As a consequence, there is considerable theoretical basis for interpreting the data generated from these tasks.

In addition to identifying generic tasks present in advanced tactical aircraft, the cockpit analysis also suggested that a key aspect of tactical missions was shifts in the difficulty and/or complexity of flight tasks which occur during the course of a mission. The present study was therefore designed to provide information about performance on the tracking and TAT tasks at a variety of levels of task difficulty and complexity. This information will also be valuable for developing appropriate tasks to study the effects of adaptive automation. As discussed earlier, it may be desirable to invoke an adaptive automation system when tasks increase in difficulty since during these periods of time automation may be most beneficial. Thus, obtaining baseline performance data on tasks which increase in difficulty without automation will provide important comparative data for assessing potential benefits of automation during these instances.

A number of performance theories have been proposed in the literature which describe how the concurrent performance of multiple tasks effect each other and overall performance. For instance, resource theory provides a convenient and useful tool for predicting possible outcomes for the manipulations utilized in this study (Kahnemann, 1973; Navon & Gopher, 1979; Wickens, 1984). According to this

theory, task performance is directly related to the ability of the operator to allocate available processing resources to cope with current task demands. As long as these demands do not exceed processing capability, increases in task demand will not effect performance, i.e. there will be no reduction in performance. Instead of a reduction in performance efficiency, resource theory suggests that more resources are deployed, or existing resources are used more efficiently. Once all available resources are dedicated to performing a task, any further increase in the difficulty of a task will result in a corresponding decrease in task performance. At these levels of task difficulty, differences between tasks, and the effects of adding or taking away tasks can be clearly seen. If this version of resource theory is accepted, it becomes apparent that one additional goal of the baseline study must be to ensure that the tasks used do not overload subjects to such a degree that uniformly poor performance is found, or underload the subjects to a degree that no changes are seen in subject performance. Either result would make the interpretation of the results problematic.

The issue of task underload or overload becomes even more critical in the context of automation. The anticipated result in applying automation is that, in effect, a task is no longer being performed by the human operator. If the size of this benefit is going to be measured in order to assess to what degree operator resources are released for application to other tasks, it is necessary that the remaining (non-automated) tasks still impose an appropriate level of workload such that the magnitude of change is measurable. Further, if a complex task (e.g. flying an airplane), consists of a variety of component tasks, and then the effects from automating various combinations of those component tasks are going to be compared, it must be determined if those tasks combinations are likely to be using similar levels of resources. In other words, that the removing of a component task through automation does not so underload the operator that the resulting performance measures do not reflect the subject's effort in performing the task.

The notion of underload/overload has theoretical importance in addition to the practical issues of data collection. These concepts are embodied within arousal theory (Broadbent, 1971; Easterbrook, 1959; Hockey, 1976; Yerkes & Dodson, 1908). According to this explanation of human performance, performance efficiency is best when the level of stimulation associated with a task is neither too little nor too great, i.e., an optimal level of stimulation is achieved. This theory could be applied to understanding human performance in adaptively automated systems. It is possible that automation of system functions should sufficiently reduce task stimulation that a situation of underarousal could arise, and would therefore result in a decrease in task performance. Equally likely is the possibility for manual task demands to create a level of overarousal which would then result in a decrease in task performance. From this perspective, it would be important for an adaptively automated system to maintain a balance between task difficulty and automation such that a state of equilibrium at the optimal level of task stimulation is maintained. Although this position is very appealing, it has one major drawback for predicting the outcome of the present study. Since this is a baseline study no a priori knowledge is known about levels of task stimulation which will be produced by the task utilized. Thus, it is impossible to determine where the tasks are positioned on the arousal curve, and interpretation of the results from this perspective can only be made post-hoc.

Although the arousal position does not allow predictions to be drawn about the outcome of the present study, resource theory does provide some direction. Once appropriate levels of simple task performance are found for the tracking and TAT tasks, it can be predicted that:

(1) Performance on any task by itself would be better than when the task was performed in conjunction with a second task;

(2) A direct relationship between performance and task difficulty/complexity would be found such that performance on the easy tasks was always greater than performance on the hard tasks.

(3) When both tasks were present, the best overall performance would occur in the combination containing both easy versions of the tasks followed by pairs in which only one of the tasks in the pair was a hard task. The worst performance was expected in the task-pairing in which both tasks were hard tasks.

METHOD

SUBJECTS

A total of six Naval Air Development Center employees were used across three iterations of the baseline study. The results from the first two iterations served to debug the experiment apparatus, and optimize the task characteristics and subject protocol. Only the results of the final iteration will be discussed here. In this study one woman and two men served as subjects. All three subjects had normal, or corrected to normal, vision. One of the men was left handed while the remaining subjects were right handed. None of the subjects had any known physical anomaly that would impact task performance.

APPARATUS

The experiment was conducted using the NADC Reconfigurable Cockpit (RC). The RC is a mid-fidelity, single pilot, fixed-base, flight simulator. The system was originally designed to develop and validate glass-cockpit displays and controls. However, for the baseline study its capabilities were modified to serve as a flexible testing environment for human performance research. The current experiment required the development of a two-dimensional tracking task and a decision making task (also referred to as the Tactical Assessment Task or TAT). Both tasks were presented on 6" Cathode Ray Tube (CRT) displays which were part of Multi-Function Displays (MFDs) embedded in the RC cockpit. Subject responses to the TAT were made by depressing MFD buttons while the tracking task was controlled through a conventional flight control stick. Although the RC was used to run and coordinate the experiment, limitations in its original architecture dictated that an external Zenith 286 computer system incorporating a Scientific Solutions LabTender card would be required to provide millisecond timing resolution for subjects' responses to the TAT.

The tactical assessment task was displayed on a Barco CM-22 video monitor located in the upper center quadrant of the display panel (See Figure 1). The TAT display format consisted of an own-ship reference surrounded by two range rings (See Figure 2). Targets appeared in the top half of the display at a predetermined rate throughout each experiment session. Targets moved down, and to some degree across, the display at a fixed rate such that all targets passed tnrough the inner and outer range markers, and then off the monitor. Subjects were to classify the targets as Enemy or Friendly as soon as they crossed the outer range marker. Twenty percent of the targets were defined so that they appeared either touching or just inside the outer range ring, and therefore required immediate responses from the subject. These "pop-up" targets had the effect of making the TAT somewhat less predictable, and were intended to mimic the behavior of radar displays encountering low observable aircraft, electronic jamming, or low level flight. From a theoretical viewpoint, the "pop-up" targets were added to ensure that subjects continually monitored the TAT task by reducing the predictability of signal events. With the addition of this type of target, subjects could not anticipate the occurrence of the next signal given the apparent distance and speed of oncoming targets. Thus, subjects were less able to take task contingent "time outs" from monitoring. The lack of such time-outs has been shown to increase the overall difficulty of monitoring tasks (Jerison and Pickett, 1964; Richter, Senter, and Warm, 1981; Scerbo, Warm, and Fisk, 1987). The dependent measures used for the TAT task were percent correct and response time. Both of these measures were utilized because it is not possible to interpret response time or accuracy without assessing if subjects have shifted their performance criterion between them, i.e. there has been a analog of a speed-accuracy tradeoff (Briggs & Shinar, 1972; Pachella, 1974).

The tracking task utilized was a first-order, two-dimensional compensatory task. The task was displayed through a Sony PVM-8221 composite video monitor mounted in the upper right corner of the cockpit (See Figure 1). The task display format consisted of a red colored "target" symbol and a white colored "own-ship" symbol, as

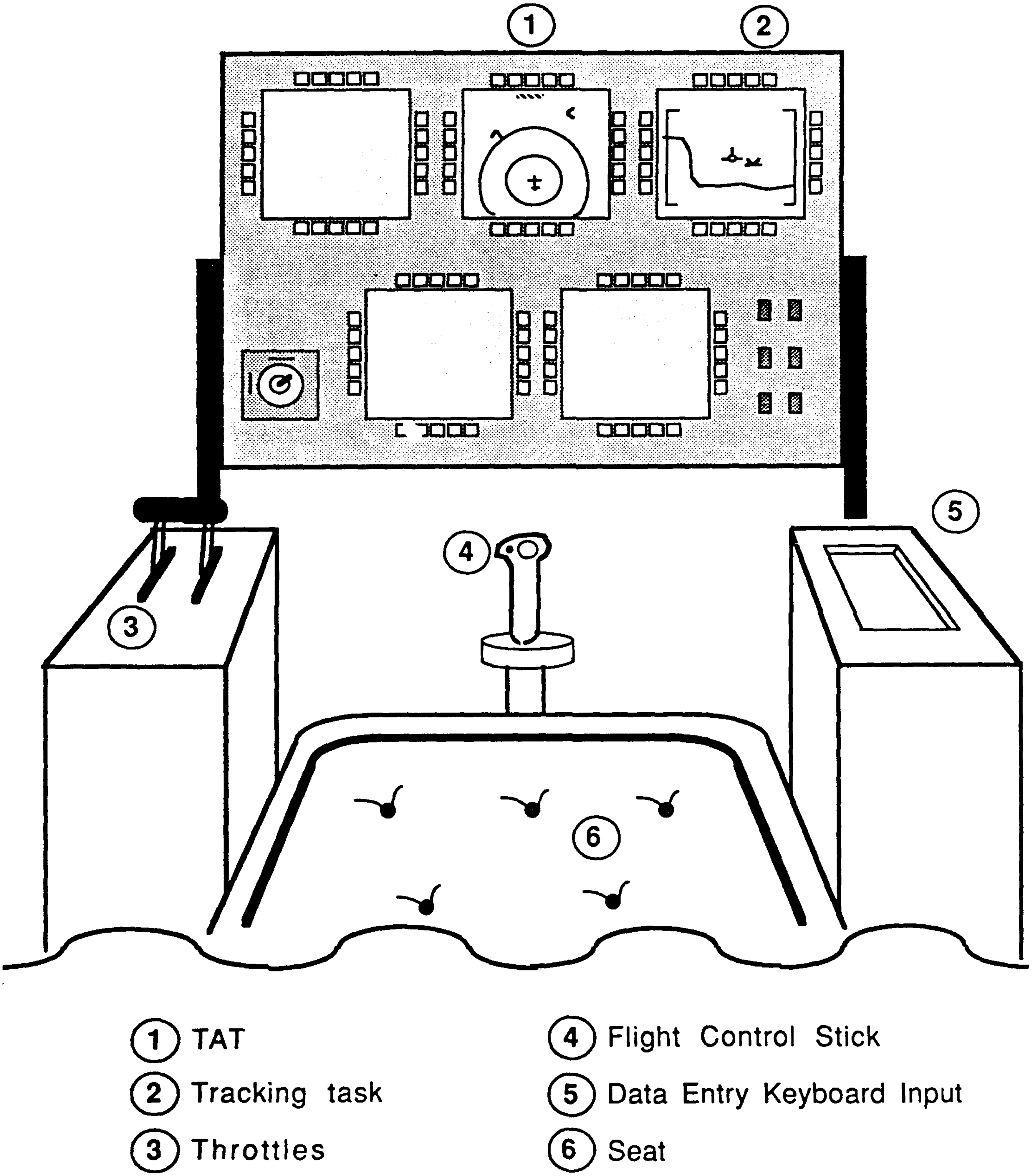
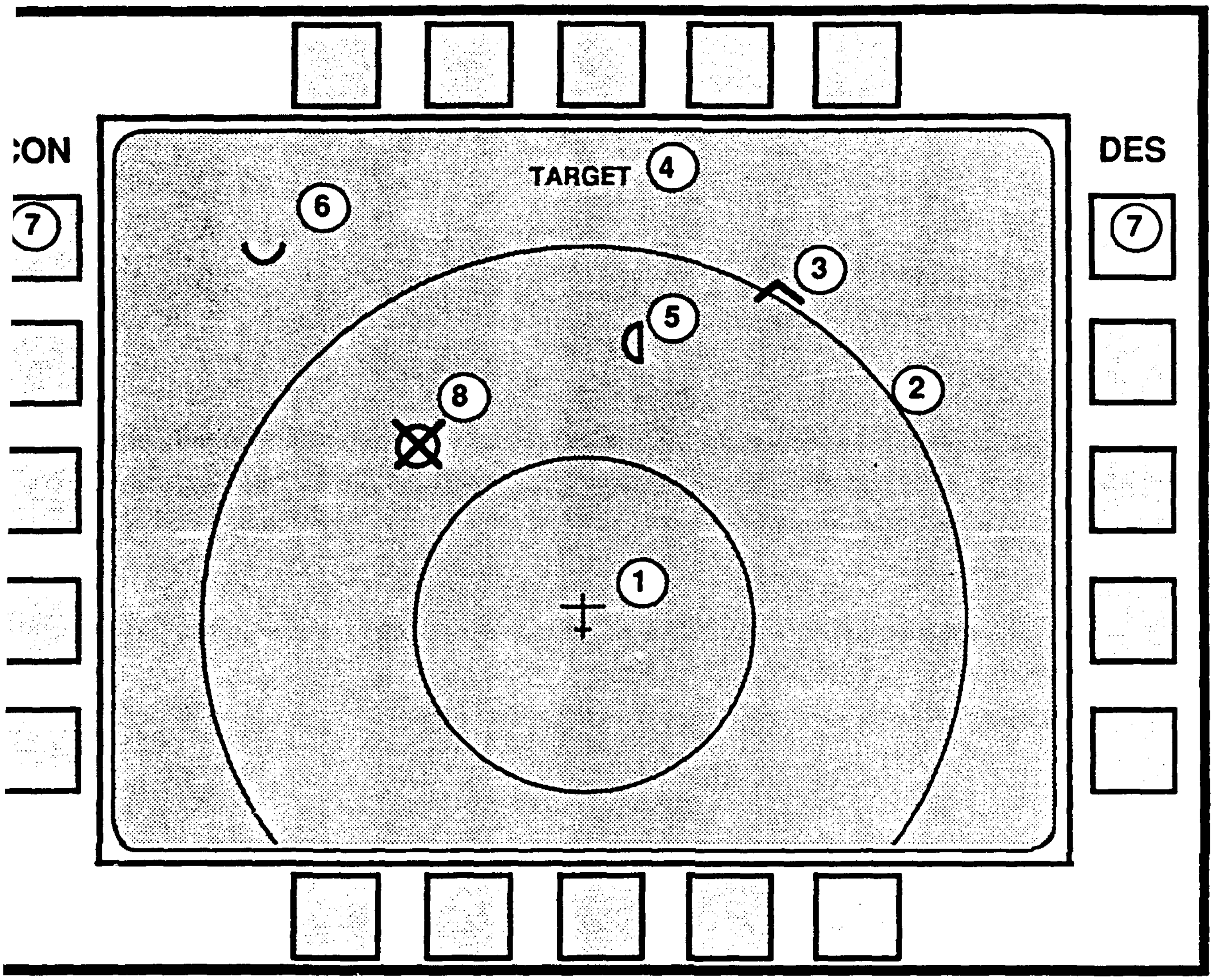


Figure 1. NADC's Reconfigurable Crewstation Simulator.



1. Ownship
2. Outer Range Ring (As targets approach they must be identified)
3. Target (to be identified)
4. `TARGET' Prompt- signals that a target must be identified
5. Target which has been correctly identified
6. Target which will need to be identified
7. Response buttons
8. Target which has been missed or incorrectly identified

Figure 2. Tactical Assessment Task (TAT) Display Format.

shown in Figure 3. Both symbols were approximately 1 by 0.5 cm in size. The tracking task display also contained a ground reference symbol and a set of altitude scales to assist the subject in judging target movements. The ground symbol moved appropriately in response to the subject's control inputs, while the altitude scales remained fixed. Both of these aids were presented in green, and care was taken to ensure that both the target plane and own-ship could not bisect these lines. As with many aircraft displays, the self-reference point, or own-ship, remained as a fixed point in the center of the monitor. The dependent measure used for this task was Root Mean Square Error (RMSE)[1].

PROCEDURE

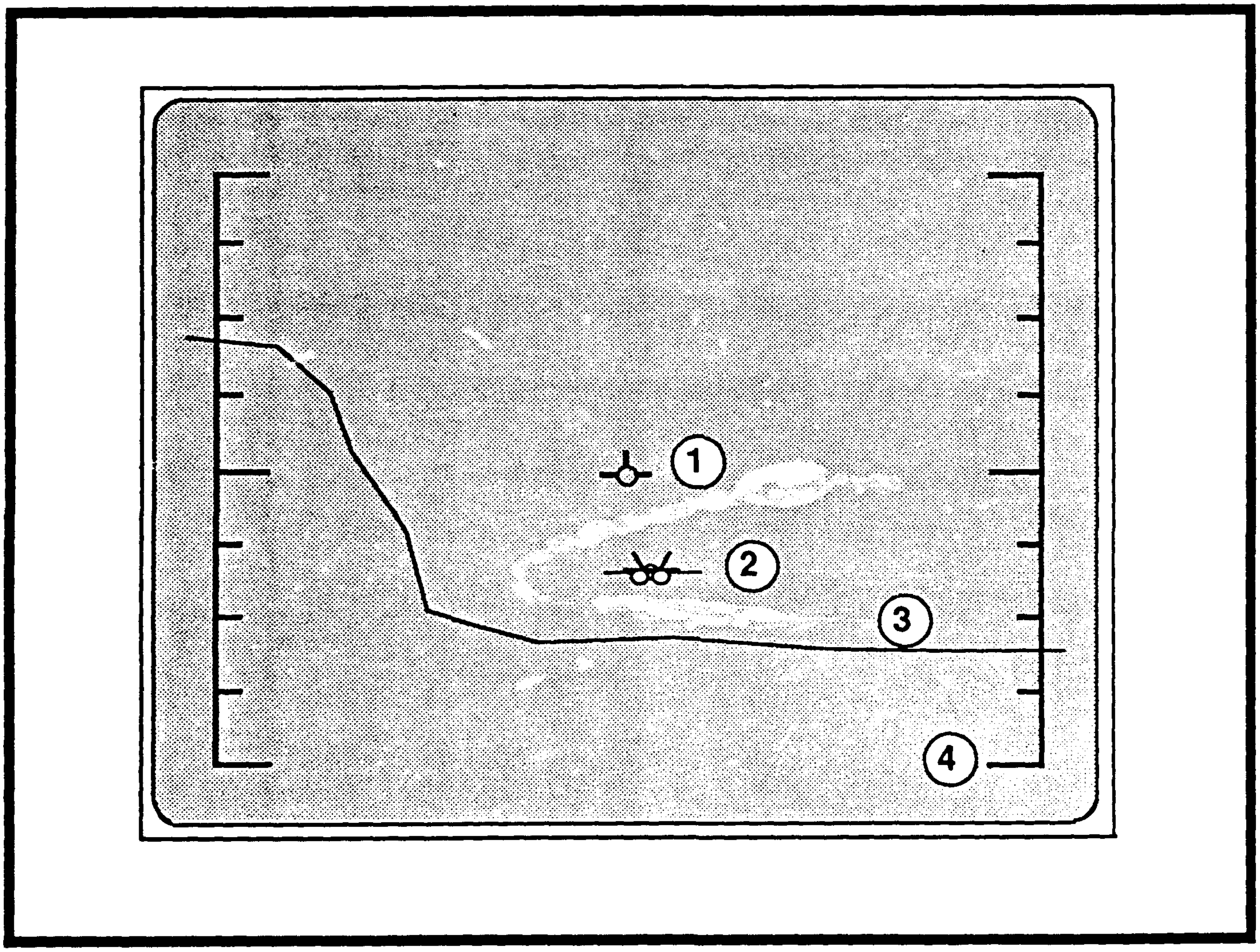
Several days in advance of the first experiment sessions, subjects were given a briefing package. The package contained a thorough explanation of the experiment, a verbal description of the tracking task and the TAT task, as well as copies of Figures 1, 2, and 3. Subjects were also instructed to memorize the symbol set presented in Figure 4 so that they could identify each symbol with 100% accuracy. Self-test practice sheets were provided to facilitate this process. Prior to the start of each experimental session, a short test of the symbols was administered to the subjects to ensure that correct identification was possible. Copies of these materials may be found in Appendix 1.

In order to ensure that the initiation of subject's responses were consistent, the word "TARGET" would appear at the upper center of the TAT display when a target

[1]The procedure used in collecting data involved storing actual horizontal and vertical deviations in pixels at a rate of 10 Hz. During post-processing, these data were then converted to RMSE through the use of the formula (Poulton, 1974):

$$RMSE = \sqrt{\frac{\sum (\Delta X_i)^2 + (\Delta Y_i)^2}{n}}$$

where X = Ordinate, Y = Abscissa, n = Number of Samples.



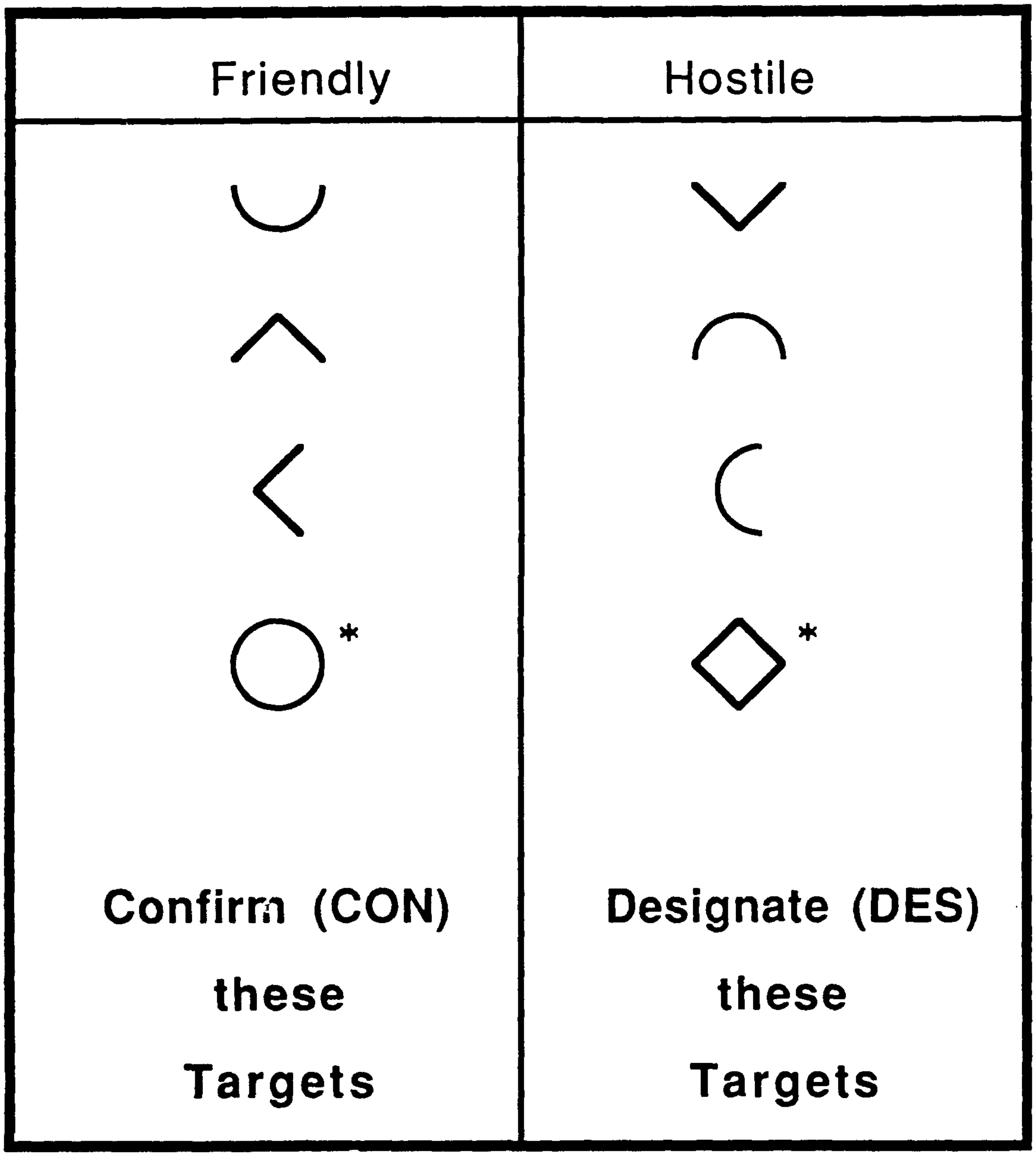
(1) Ownship bug (fixed to display)

(2) Target (to be tracked)

(3) Ground representation

(4) Altitude scale

Figure 3. Tracking Task Display Format.



* This pair of symbols was used in the 2-symbol type conditions.

Figure 4. Symbols Used in the Tactical Assessment Task.

became eligible for a response. Timing started when the TARGET symbol appeared. Only one target was eligible for response at any given time. Responses were made by pressing one of two MFD buttons surrounding the TAT. The upper left button was labeled **CON** and was used to CONfirm friendly targets. The upper right button was labeled **DES** and was used to DESignate enemy targets (See Figure 2). Subjects had 3 seconds from the time the "TARGET" symbol appeared to make a detection response. Responses occurring after the 3 second interval were considered false alarms, and were eliminated from the analyses. At all times, subjects responded to TAT targets using the index finger of their left hand. Between TAT events, subjects rested their hand on a fixed position on the left armrest. Mean distance to the response buttons on the TAT MFD was 57 cm.

The difficulty of the TAT was manipulated in two different ways. First, the rate of critical events was changed. The low event rate (slow condition) had an average inter-stimulus interval (ISI) of 15 seconds with a range of 12 - 18 seconds, while the ISI for the high event rate (fast condition) was 10 seconds with a range from 7 - 13 seconds. TAT difficulty was also varied by changing the number of symbol types presented. This manipulation was conceptually analogous to changing the number of items which had to be remembered, i.e. memory set-size. In the easy condition, only two of the possible eight symbols, the diamond and circle, were used, (See Figure 4). All eight symbols seen in Figure 4 were used in the hard condition.

With regard to the tracking task, subjects were instructed to track the target to the best of their ability by manipulating the force stick with their right hand only. Perfect tracking was defined as keeping the own-ship reference centered on the target at all times. Two target driving frequencies, the rate of direction changes, were used to create two levels of difficulty in the tracking task (easy and hard). The easy tracking condition was defined as having a driving frequency of 0.061 Hz, while the hard condition was defined as having a driving frequency twice that of the easy (driving frequency = 0.121 Hz). A central, floor-mounted force stick was used for

control inputs to the tracking task, and was located as in a conventional cockpit configuration (See Figure 1). The force requirements to operate the flight control stick on the simulator were similar to those of an F-14 in normal flight.

The factorial combination of the tracking and TAT tasks at each level of task difficulty created a total of 14 conditions, as can be seen in Table 2. Six of these groups consisted of "simple" tasks in which subjects were required to perform either the tracking task <u>or</u> the TAT. The remaining eight conditions contained "complex" tasks in which subjects were required to perform <u>both</u> the tracking and TAT tasks simultaneously. Each subject participated in all of the experiment conditions creating a completely within-factors design. In order to avoid problems with fatigue, subjects participated in three 1 to 1 1/2 hour experiment sessions distributed over three consecutive days. The first session consisted of a ten-minute review of the subject briefing material, followed by three five-minute blocks of training (1 block simple tracking, 1 block simple TAT, 1 block complex task consisting of both tracking and TAT). All training was done with the easy task difficulty levels (Tracking - easy, TAT - slow event rate and two symbol types). The training was then followed by four 10-minute experiment blocks. Sessions two and three began with two minutes of practice on each of the three training task combinations used in session 1 (in a randomly selected order) followed by five 10-minute experiment blocks. Conditions were randomly assigned to experiment blocks, with the constraint that some simple and complex task conditions had to occur each day. Experiment blocks within each session were separated by a five-minute rest period.

Table 2. Experiment Design

	Tracking	TAT	
		# of Symbols	Event Rate
Simple Task Condition		8	Slow
		8	Fast
		2	Slow
		2	Fast
	Hard		
	Easy		
Complex Task Condition	Hard	8	Slow
		8	Fast
		2	Slow
		2	Fast
	Easy	8	Slow
		8	Fast
		2	Slow
		2	Fast

RESULTS

While the experiment design would allow an analysis of variance (ANOVA) to be performed, the limited number of subjects used in the final iteration of this study does not create sufficient data to justify its use. Therefore, the data are presented, summarized and discussed without the use of formal statistical tests. Hence, all of the results and discussion must be considered tentative until replicated in later CAS research. The data pertaining to each of the dependent measures will be presented in both graphic and tabular form. Standard errors of the means will be presented in both formats so that an informal evaluation of effect size and significance can be made.

The most straightforward approach to assessing the complex effects on performance is to evaluate the effects on simple task combinations (only the tracking or the TAT task) independently from those of complex task combinations (both the tracking and the TAT tasks). Once these have been outlined, differences between performance on the simple vs. complex tasks will be discussed.

Simple Task Results

Tracking Task. Mean RMSE for all subjects in all conditions are presented in Table 3, and are graphically portrayed in Figure 5. As can be seen in Figure 5, RMSE was lower for the easy as compared to the hard condition in the simple task combination. This effect was fairly robust as can be seen by the non-overlapping standard error bars for these conditions.

Tactical Assessment Task (Reaction Time). Mean of median reaction times for all task combinations are presented in Table 4, and in Figure 6. One should note that the reaction time data was more variable relative to the effect sizes than either the RMSE or, as will be seen below, the percent correct data. Therefore, the results

Table 3. Mean RMS Error for Each of the Experiment Conditions.

	Tracking	TAT: # of Symbols	TAT: Event Rate	RMSE	MARGINAL MEAN RMSE: Event Rate	MARGINAL MEAN RMSE: Symbols	MARGINAL MEAN RMSE: Tracking	MARGINAL MEAN RMSE: Simple / Complex
Simple Task Condition		8	Slow					15.40
		8	Fast					
		2	Slow					
		2	Fast					
	Hard			18:40 (2.15)			15.40	
	Easy			12.40 (1.32)				
Complex Task Condition	Hard	8	Slow	26.80 (1.62)	27.90	26.09	26.79	22.03
		8	Fast	25.37 (0.65)	25.64			
		2	Slow	29.00 (7.50)		27.46		
		2	Fast	25.91 (1.55)				
	Easy	8	Slow	20.30 (7.44)	18.71	18.55	17.26	
		8	Fast	16.79 (1.28)	15.80			
		2	Slow	17.12 (3.87)		15.97		
		2	Fast	14.81 (1.25)				

NOTE: NUMBERS IN PARENTHESIS ARE THE STANDARD ERROR OF THE MEAN.

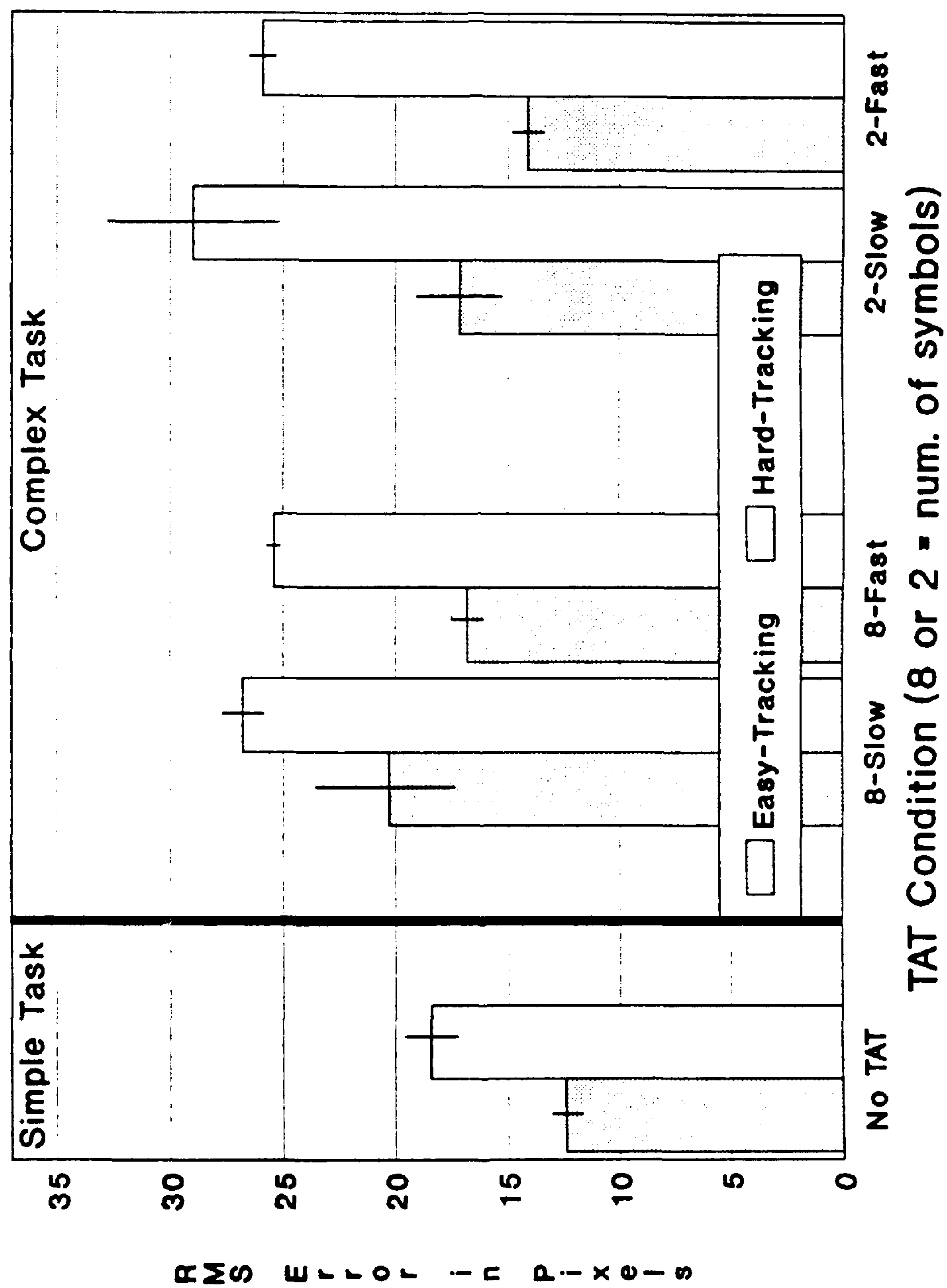


Figure 5. Mean RMS Error for Each of the Experiment Conditions.

Table 4. Mean of Median Reaction Times in Seconds for Each of the Experiment Conditions

	Tracking	TAT # of Symbols	TAT Event Rate	RT	MARGINAL MEAN RT Event Rate	MARGINAL MEAN RT Symbols	MARGINAL MEAN RT Tracking	MARGINAL MEAN RT Simple / Complex
Simple Task Condition		8	Slow	1.33 (0.16)	1.315	1.395		1.412
		8	Fast	1.46 (0.12)				
		2	Slow	1.30 (0.10)		1.430		
		2	Fast	1.56 (0.05)	1.5105			
	Hard							
	Easy							
Complex Task Condition	Hard	8	Slow	1.60 (0.08)	1.595	1.585	1.585	1.655
		8	Fast	1.57 (0.12)				
		2	Slow	1.59 (0.08)		1.585		
		2	Fast	1.58 (0.04)	1.575			
	Easy	8	Slow	1.69 (0.02)	1.715	1.710	1.725	
		8	Fast	1.73 (0.12)				
		2	Slow	1.74 (0.02)		1.730		
		2	Fast	1.72 (0.02)	1.725			

NOTE: NUMBERS IN PARENTHESIS ARE THE STANDARD ERROR OF THE MEAN.

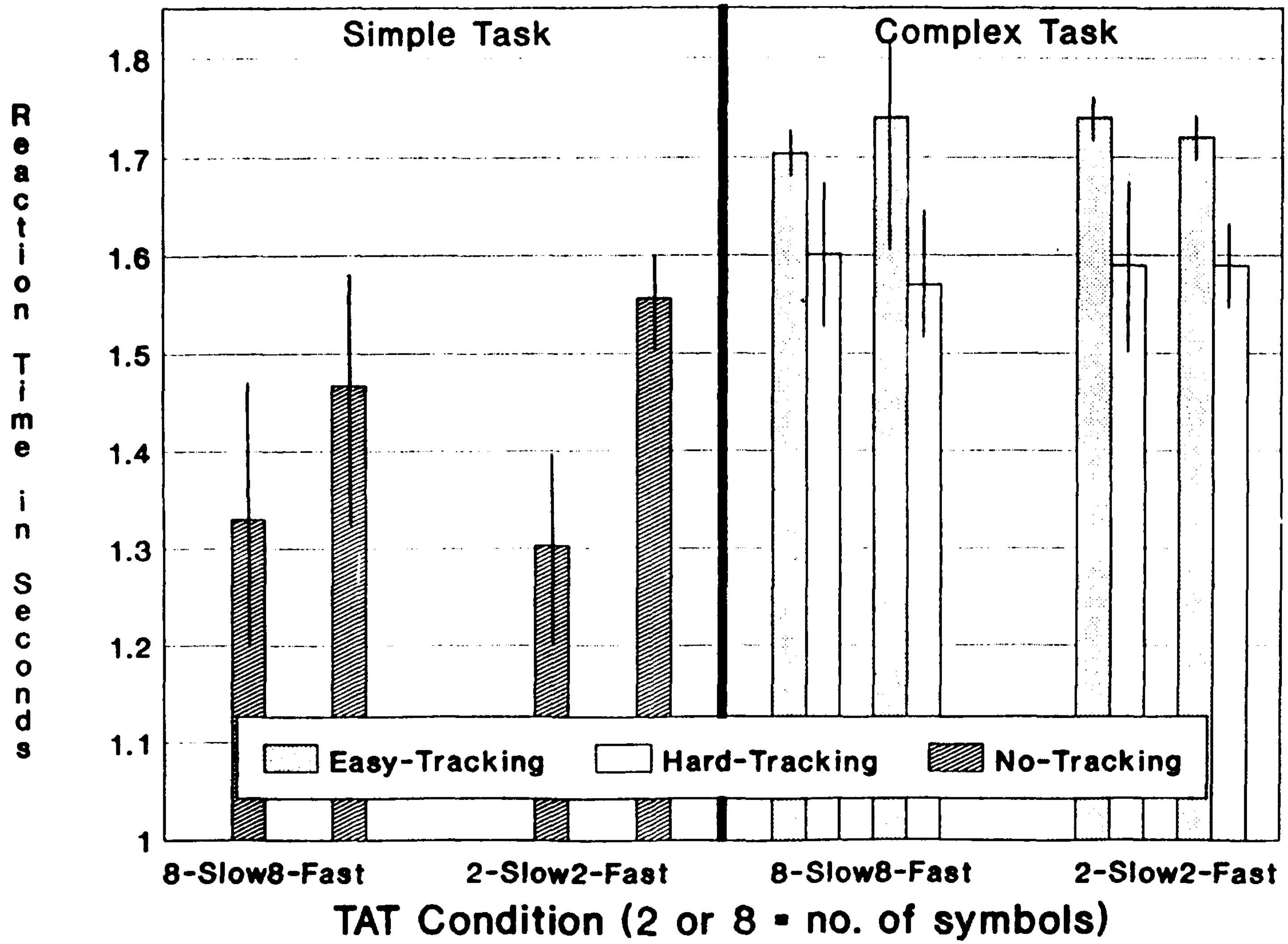


Figure 6. Mean of Median Reaction Times in Seconds for Each of the Experiment Conditions.

based upon this measure are less conclusive. It would appear, however, that there is a main effect for event rate in the simple task data. Reaction times for the slow event rate conditions were faster than those to the fast event rate conditions. The data do not show an effect for symbol types used, nor does there appear to be an interaction between event rate and symbol type.

Tactical Assessment Task (Percent Correct). Mean percent correct data are presented in Table 5 and Figure 7. Perhaps the most immediately noticeable result in both the table and the figure is the very high level of performance for all of the task conditions. Equally evident is the very low variability of these data. Together, these results suggest that performance changes may have been minimized due to a ceiling effect. Despite this problem, several interesting effects emerged as can be seen in Figure 7. With regard to the simple task groups, no overall differences for event rate, or number of symbol types is present. There does, however, appear to be an interaction between event rate and number of symbols. With reference to the conditions in which 8 symbol-types were used, no difference in percent correct between the slow and fast event rates is present. However, in the 2 symbol-type groups, a higher percent correct was achieved in the slow event rate condition than the other three conditions, and a lower percent correct is present in the fast event rate condition than is present in the other conditions.

Complex Task Results

Because the complex task conditions involve performance on both the tracking and the TAT tasks, the discussion of performance effects in these conditions will be discussed in terms of dependent measures as opposed to task type (tracking or TAT).

RMSE. As can be seen in Figure 5, in all of the complex task conditions RMSE was lower for the conditions in which the TAT was coupled with the easy tracking task than those in which it was paired with the hard tracking task. There also is a tendency for task conditions in which the fast TAT event rate was performed in

Table 5. Mean Percent Correct for Each of the Experiment Conditions

	Tracking	TAT # of Symbols	TAT Event Rate	% CORR.	MARGINAL MEAN % CORR. Event Rate	Symbols	Tracking	Simple / Complex
Simple Task Condition		8	Slow	96.67 (2.20)	97.92	96.55		96.75
		8	Fast	96.43 (1.79)				
		2	Slow	99.17 (0.83)	95.58	96.95		
		2	Fast	94.73 (2.34)				
	Hard							
	Easy							
Complex Task Condition	Hard	8	Slow	95.79 (0.86)	96.23	97.06	96.87	95.93
		8	Fast	98.33 (0.00)				
		2	Slow	96.67 (3.33)	97.50	96.67		
		2	Fast	96.67 (1.93)				
	Easy	8	Slow	97.50 (1.44)	95.81	96.24	94.99	
		8	Fast	94.98 (1.66)				
		2	Slow	94.12 (2.20)	94.16	93.73		
		2	Fast	93.33 (3.33)				

NOTE: NUMBERS IN PARENTHESIS ARE THE STANDARD ERROR OF THE MEAN.

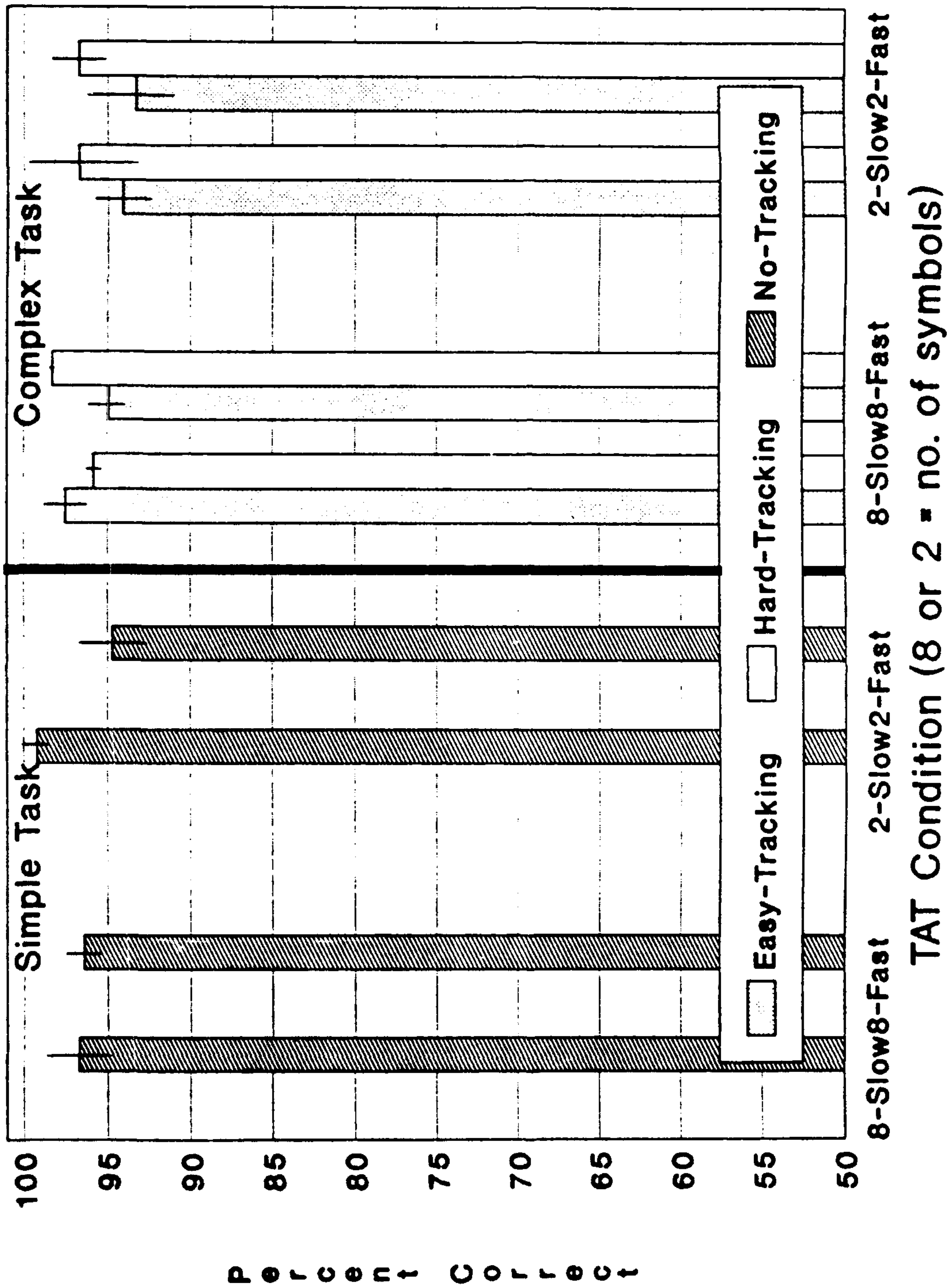


Figure 7. Mean Percent Correct for Each of the Experiment Conditions.

conjunction with the tracking task to have a lower RMSE than conditions in which the slow TAT event rate was utilized. No differences emerged as a consequence of symbol types used, and no interactions between any of the three factors (tracking difficulty, TAT event rate, and TAT symbol types) were present.

Reaction Time. Illustrated in Figure 6 are the effects on reaction time for the complex task groups. Most noticeable in the figure is that reaction times to signals in the TAT were faster when this task was coupled with the hard tracking task than when it was coupled with the slow tracking task. No other main effects or interactions between TAT event rate, symbol types, or tracking difficulty are evident in the figure.

Percent Correct. Percent correct data for the complex task groups is presented in Figure 7. Once again, interpretation of these data may be difficult since ceiling effects may be present. With this in mind, it appears as though there are no main effects for tracking difficulty, TAT event rate, or symbol types. There does, however, appear to be a subtle three-way interaction between these factors. With regard to the combinations of tracking and TAT in which only 2 symbol types were used, a greater number of signals were identified in the conditions in which the hard tracking task was present than those in which the slow tracking task was used. This effect was not modified by event rate. This overall pattern of results does not appear in the conditions in which all eight symbol types were used. In this case, the effects brought about by the increase in tracking difficulty were moderated by event rate. In the slow event rate conditions, performance when the task was coupled with the easy tracking task exceeded that of the condition in which the hard tracking task was used. The reverse occurred when the tracking tasks were combined with the fast event rate TAT.

Table 6. Pop-up vs. Normal Signals for Percent Correct and Reaction Time: Simple and Complex Task Conditions

Percent Correct

Task Condition	NORMAL	POP-UP	$\bar{X}$
SIMPLE	96.6	98.2	97.4
COMPLEX	97.5	95.5	96.5
$\bar{X}$	97.05	96.85	96.95

Reaction Time

Task Condition	NORMAL	POP-UP	$\bar{X}$
SIMPLE	1.43	1.84	1.64
COMPLEX	1.59	1.97	1.78
$\bar{X}$	1.51	1.91	1.71

Performance Differences Between Simple and Complex Tasks

The comparisons that follow are important for their potential implications for automation. They will be re-examined in greater detail as part of the discussion section.

RMSE. With regard to tracking task performance (Figure 5) within each level of tracking task difficulty RMSE was always greater for the complex as compared to the simple task conditions. However, overall RMSE for the complex conditions in which the easy tracking task was utilized were not higher than those found for the (simple) hard tracking task performed alone.

Reaction Time. As was found with RMSE, it can be seen in Figure 6 that overall, reaction times were longer in the complex task conditions than they were in the simple task conditions. Also evident is a tendency for the simple task reaction times with the fast event rate to be similar to those of the complex task conditions in which the TAT was coupled with the hard tracking task.

Percent Correct. No differences between simple and complex task performance, were found for accuracy (Figure 7). Once again, a lack of differentiation between conditions with regard to percent correct may reflect a ceiling effect.

Pop-up vs. Normal Targets

As can be seen in Table 6, slight differences between pop-up and normal targets were found on either measure of performance (percent correct and reaction time). The changes were in the anticipated direction, i.e. increased reaction times and RMS error for pop-ups relative to normal targets. Further, similar results were found in the complex and simple task conditions and there were no interactions between target type (pop-up or normal) and the simple or complex tasks were found.

DISCUSSION

The present study is the first in a series of cockpit automation studies (CAS) addressing human performance issues in adaptive automation as it applies to the tactical aircraft cockpit. Since this effort represents the first in a line of programmatic studies, this experiment was designed to accomplish the following goals: (1) Adapt NADC's Reconfigurable Crewstation (RC) to implement the tasks to be used in the CAS program, and collect appropriate human performance data. (2) Develop a set of research tasks analogous to those found in a tactical aircraft cockpit which are also comparable to standard laboratory tasks used to study human performance. (3) Collect and analyze preliminary performance data on several versions of the baseline tasks in order to ensure that empirically different levels of task difficulty were developed. (4) Develop an initial understanding of how multiple cockpit tasks impact performance on each other, as well as how performance of the tasks in combination relate to performance of the tasks when performed alone. These data will be used to determine the effects on human performance due to automation and release from automation which will be evaluated in later studies. (5) Evaluate the performance metrics used to ensure that they reflect meaningful differences in performance and are sufficient for understanding performance on cockpit tasks. The results of the CAS-1 study suggest that almost all of the goals have been attained. Each of these goals will be discussed in turn in the remainder of the discussion as well as suggestions for alternative procedures and performance indices when appropriate.

Appropriateness of the RC to Human Performance Research

The RC was successfully modified to allow appropriate research tasks to be developed. Several major alterations, including an external timing mechanism to monitor subjects' responses to the Tactical Assessment Task (TAT) were required. However, it was possible to obtain accurate and reliable data. In addition to the immediate goal of task development for the CAS-1 experiment, the RC was also

identified as a highly flexible and powerful research vehicle that can be further adapted to accommodate future goals of the CAS program.

Task Development: Implementation and Levels of Task Difficulty

A first-order tracking task and a tactical assessment task (TAT) have been successfully implemented on the RC. After several iterations in developing these tasks, manipulations of driving frequency, event rate, and number of symbols were used to alter task difficulty. The results of the experiment suggest that the manipulations of task difficulty or complexity in the simple task conditions were, for the most part successful, and generally support a resource view of human performance. With regard to the manipulation of driving frequency in the tracking task, the data suggest that doubling the driving frequency significantly reduces tracking task performance (increases RMS error). This suggests that subjects utilize more resources when performing the tracking task at high driving frequencies than at low frequencies. With regard to the TAT, the results suggest that increasing the event rate increases subjects' reaction times but does not effect their detection accuracy. According to resource theory, such a result suggests there is a direct relationship between the amount of resources required and the number of events that must be processed. Such a result is not uncommon, and has been found using other tasks which feature discrete events (Gluckman, 1990). No effects for TAT performance were found for the manipulation of symbol set size, and no differences in detection accuracy were found for any of the manipulations of the TAT.

The overall lack of sensitivity of the percent correct measure, and the general lack of differentiation between the two symbol set sizes were not anticipated. Upon review of the training and experiment procedures, however, several explanations for these results were found. First, subjects were trained to one hundred percent proficiency for symbol identification prior to the experiment. Second, because a sufficiently long period of time was given for subjects to respond to signals (3 seconds), few were missed, and subjects could afford to take time to ensure high

accuracy. Lastly, the memory set sizes that were utilized in the present study (2 or 8 symbols), did not exceed the limits of working memory (7 $\pm$ 2 items) (Miller, 1967). Therefore, once a target became active, it could readily be compared against the symbol representations in memory.

The last manipulation that was utilized in this experiment was to make target occurrences more uncertain by adding pop-up targets. As would be anticipated, both percent correct and reaction times to these stimuli tended to be degraded relative to the normal stimuli. Although the results are not compelling, the theoretical and ecological rationale for incorporating pop-up targets is important and should be investigated further in future CAS studies.

In addition to their theoretical importance, the results of the simple task performance data have some interesting ecological implications which provide some direction for future research. It is possible with current technology, that the number of active targets that might appear on a Radar Intercept Officer's (RIO) radar screen might be greater or less than the event rates utilized in this study. It is less likely, however, that the number of different symbols which would be used to designate both friendly and unfriendly targets would exceed 8 (the number used in the present experiment). Moreover, RIO training procedures would be at least as stringent as those used in this experiment and would, therefore, ensure that few mistakes in identification would occur. These ecological factors suggest that future modifications on the TAT should focus on changes in the event rate rather than the complexity of the symbol set. It is possible that further increases in event rate will effect both speed and accuracy rather than only a shift in the speed with which subjects can identify targets. This might occur because more targets will need to be identified, the relative amount of time to identify targets will be reduced, and subjects will be afforded less time to consider their response choice.

Complex Task Performance: Task Interaction and Comparison to Simple Tasks.

Several important findings are present in the complex task data which address goal number 4; understanding complex task performance and how it differs from simple task performance. This goal is critical to the CAS program because the complex task conditions are more representative of real cockpit activities. The results of the manipulations of task difficulty in the complex task groups were generally consistent with those of the simple task groups. As with simple task performance, the manipulation of driving frequency in the tracking task had the most pronounced effect on task performance. Also consistent with the simple task results, the number of symbol types used had no effect on performance as shown by either TAT dependent measure (percent correct and reaction time).

Unlike the simple task results, no main effect for event rate emerged in the performance data for the complex task groups on either dependent measure. However, a trend for a three way interaction of event rate, driving frequency, and number of symbols was present in the percent correct data only. This result was not anticipated and cannot be accommodated by either a resource or arousal explanation. One should note that the effect size for this three-way interaction is very small, and from an operational perspective represents a difference in detection accuracy of only one or two signals in any condition. Therefore, it is likely that this interaction is a result of a methodological constraint as opposed to differences in resource drain or task stimulation as would be suggested by the resource or arousal models.

Although the percent correct data did not provide much insight into complex task performance, several important results emerged in the reaction time and RMS error data. The pattern of effects that manipulating tracking task difficulty had on performance was remarkably consistent both within the complex task conditions and between the simple and complex conditions. Overall, both RMS error and reaction times were elevated by the need to engage in both the TAT and tracking tasks

relative to only having to perform one of these tasks. This result is consistent with a resource view of human performance. In this case, sufficient amounts of additional resources may have been necessary to perform both tasks in the complex task conditions that performance was reduced relative to simple task performance. The specific nature of the decrease in performance in the complex task groups is quite interesting. If one looks at the results from the perspective of changes produced by altering the tracking task difficulty a consistent pattern emerges between the reaction time and RMS error measures. When the tracking task is easy, RMSE is low and reaction time is slow. When tracking difficulty is hard, RMSE is high but reaction time is fast.

From a resource theory perspective, one might not find a trade-off in performance efficiency, such as the one described above, to be unusual. In fact, these have been explicitly described in resource theory as a performance operating characteristic (POC) (Wickens, 1984). A POC represents the optimal level of performance on a set of tasks that must be processed concurrently. At each end of the POC curve is the level of performance that would be attained if only one of the tasks had to be performed. Along the function connecting these endpoints are performance levels when both tasks are performed concurrently. The process of constructing a POC curve for any given set of tasks normally involves systematically instructing subjects to focus differing amounts of resources or attention (from 0 to 100 percent) to the performance of one of the two tasks. Using this procedure a sample set of points along the POC can be derived which describes the POC for that particular set of tasks. The data from the present study could be mapped into the framework of a POC if one assumes that the performance shifts brought about by the change in tracking task difficulty resulted in a shift in subjects' focus of attention or resource allocation strategy. If this is the case, it would have to be dependent upon some factor internal to the subjects since subjects were instructed to perform both tasks equally in all of the complex task conditions.

There remains the problem of why the tasks flip-flop according to the difficulty of the tracking task, and not the event rate of the TAT. In addition, one might wonder why the prominent effect of event rate present in the simple TAT performance was not present in the complex task conditions. One answer to these questions might be provided if one speculates about how subjects perceived the difficulty of the tasks. One factor which might influence how subjects perceive the tracking and TAT could be the amount of performance feedback provided by each task. Tracking task feedback is continuous because subjects may assess their performance on the task any time, as often as they like. When the own-ship reference is overlapping the target then the feedback is positive, otherwise, it is negative. In either case, the feedback alerts subjects to their performance and subjects are continuously afforded the opportunity to correct their actions. In the TAT, feedback for attending to the task is both positive and negative, however it can only occur with the appearance of a new target, or with a change in the status of a target to one which requires a response. No opportunity is provided to alter responses on the TAT. Because of these differences, subjects may have shifted their attention resources toward the tracking task because it provided them with a greater degree of positive feedback, particularly when the tracking task was easy. When the tracking task was hard, and the amount of time-on-target was reduced, the tracking task would be less reinforcing and therefore, relatively more positive feedback may have been provided by the TAT. Thus, subjects shifted their attention toward the TAT. With this explanation, the event rate manipulation may have had no effect because sufficient levels of resources where either drawn away from, or added to, performance of the TAT so that the effect of this manipulation was minimized. The precise reason for both the shift in performance due to the change in tracking task difficulty and the lack of an event rate effect in the complex task conditions cannot be assessed in this study.

Although overall differences between simple and complex task performance emerged, complex task performance was not always worse than simple task

performance, as was predicted based on the resource model. Upon careful inspection of the results one might note that RMS error for the hard tracking task alone was not different from RMS error on the easy tracking task when it was performed in conjunction with any of the TAT combinations. Moreover, reaction times to the fast event rate TAT conditions, when performed alone, did not appear to differ from reaction times to the slow event rate TAT when combined with the hard tracking task. Once again, the catalyst for this effect may be the driving frequency of the tracking task. Event rate and symbol set size can be eliminated as potential causes since no significant differences in complex task performance were found as a result of changes in these task manipulations.

A possible explanation for the equality of simple and complex task performance under certain conditions hinges around the potential for differences in problem solving strategies which have been implicated with regard to tracking tasks. Poulton (1974) and Wickens (1984) have noted that at certain levels of tracking difficulty, subjects change their tracking strategy from one that minimizes position errors at the expense of velocity errors to one that minimizes velocity errors at the expense of position errors. At low driving frequencies, subjects may try to precisely follow the motions of the target resulting in overcompensation; the velocity oriented approach. However, at higher frequencies, they adopt a strategy in which high frequency changes are filtered out and lower frequency changes, or general directional changes are favored; the position oriented approach. In essence, they smooth out their motions to follow more gross, obvious changes in the direction or speed of the target. The effect of this change, in terms of the dependent measure RMSE, can be a reduction in overall error under high frequency changes since less over- or under-compensation for target motion are made.

One might assume, that using the strategy which minimizes position errors, resulting in a more smooth flow, would require fewer resources than one centered on minimizing velocity errors since subjects would not have to sample for changes in

direction or velocity as often, and fewer control corrections would be required. The present results may be due to subjects' shifting their tracking strategy in the complex task conditions. This shift of focus or strategy might interact with their overall performance and the relative amounts of positive feedback they perceive as coming from the tracking and TAT tasks. Using the current measurement techniques, there is no way to determine which strategy was used by subjects in any of the conditions used in the experiment or if changes in strategy were prompted by certain combinations of tasks. This information could only be provided by adding a measure of control stick movements; e.g. control reversals in the X and Y axes. When combined with the information about the dynamics driving both the target and the output, a clear time-dependent picture of subjects' problem solving strategy could be gained.

The fact that performance on any of the complex tasks was equivalent to that of simple task performance challenges one of the basic assumptions at the heart of most automation concepts. Specifically, it is assumed that as the number of tasks that must be performed decreases, performance increases. Automation of tasks, therefore, should increase performance. The results of this study, although they represent only baseline information about non-automated tasks, suggest that this is not always the case. As a result, automation strategies in which fixed levels of automation are provided, (as is found in conventional automated systems), will not always provide performance benefits. The results do suggest that the concept of adaptive automation may, however, be viable since one of its key features is to moderate task load as suggested in Table 1.

Given the limited scope of the present results and their generalizability to real flight missions, the human performance data from this study suggest that if pilot consent is a critical aspect of the adaptive automation system, then the task that is perceived as most difficult by the pilot might be the best candidate for automation because it is these tasks that pilots are least inclined to perform. In addition, the

hard task is the one which they may be least involved with, and therefore, pilots might be more inclined to release the difficult task to automation.

The data obtained in this study could have implications for the application of partitioning and transformation strategies. It may be that the automation system should apply a strategy that maintains equilibrium in the amount of demand each task places on the pilot so that no particular task is favored and pilots are equally involved in all tasks. In this way, pilots would remain engaged with all tasks appropriately. Thus, through the appropriate use of adaptive automation, situational awareness could be maintained while overall levels of task load are reduced to manageable levels.

These conclusions are highly speculative and very limited in scope. Many additional factors including motivation, mission requirements, and technological limits will influence how the empirical results generated in the CAS program can actually be applied.

Evaluation of Measurement Procedures.

The last goal of this investigation was to validate the measurement instrumentation and procedures used in the RC to assess performance. All of the measures taken for this study proved appropriate and, for the most part, provided diagnostic information about subjects' performance and behavior. There were, however, several shortcomings which should be addressed in future CAS studies. Clearly, less information was gained about problem solving strategies subjects used than is necessary. Although RMSE provided an index of overall performance, additional information about accuracy, problem solving strategies, and perhaps resource utilization for the tracking task could have been provided by an analysis of control stick control reversals. The incorporation of these data is within the current capabilities of the RC experiment platform, and would provide valuable information to help explore the possibility that subjects adopt a smoothing strategy under certain

circumstances. From an ecological standpoint Wickens (1984) notes that such strategies are directly applicable to primary flight activities. Moreover, adopting the incorrect strategy during any particular phase of flight could have disastrous consequences. This realization provides additional justification for the addition of more advanced tracking task measurement techniques.

A second and much more complex shortcoming of the current measurement techniques is that they do not provide an index of overall problem solving strategy or a single metric of complex task performance. At the present time, little direction about how to solve this problem exists in the literature. One place to start, however, would be to look at time-line analyses of performance and incorporate a more detailed post-test debriefing that focuses on questions related to problem solving strategies. Lastly, an issue that has been raised in the automation literature, and has been suggested as a means for invoking automation is workload. Future CAS experiments might incorporate workload measurements in order to assess this issue.

Implications for Future Studies.

The complex, and often subtle effects of the interactions among the TAT and tracking task manipulations suggests that performance in such a complex task environment can not be readily predicted from single task performance, nor even similar complex tasks. The interaction effects appear to be due to the perception of the task(s) by the subject. The perception of task difficulty cause the subject to make changes in the resources made available to a complex task, and/or the shifting of a resource allocation strategy. The introduction of automation will likely complicate these effects because automation will further change the nature of the complex task (e.g. through the transformation of a task). The impact of automation may therefore be negative, e.g. under conditions where the subject is inclined to shift to a less optimal performance strategy. Such an effect would be undesirable for the application of adaptive automation, and unexpected on an intuitive basis. Future studies looking at the effects of automation on human performance will therefore

have to establish well thought out control conditions so that the impact on task performance can be more clearly understood.

In order to understand performance on tasks with a continuous control (tracking) component, future studies should collect and analyze data regarding control inputs, as well as RMSE reflecting control performance. The potential shift of continuous control strategies, e.g. smoothing the control inputs, would have the net effect of making the tracking task easier. This strategy must be detected and taken into account if strategy tradeoffs in the context of a more complex task are to be understood.

Given the complex interrelationship of performance on the tasks employed in this study, there may be less transfer from this task to actual cockpit task performance than was at first anticipated. Little data are available to indicate what level of task fidelity is necessary to accurately predict performance from relatively low fidelity simulation tasks to the highly complex and dynamic aircraft piloting task. Therefore, future studies in the program must continue to develop increasingly complex and dynamic tasks, and compare the results obtained in them to both conventional laboratory tasks and the real-world task. Only in performing such a series of studies will it be possible to ascertain what level of fidelity in task performance is necessary to predict performance in the context of adaptive automation. This issue will certainly remain a part of the CAS program in the coming years.

Future research will also continue to increase the levels of complexity of the tasks used. Another CAS experiment is currently underway to assess the impact of adding a communication task to the array of tasks (TAT and tracking tasks) used in this study. Further, a basic automation algorithm is being implemented with these tasks to determine how automation of the component tasks impacts complex task performance. The second CAS study will be followed by similar studies utilizing

alternative, and more complex adaptive automation strategies such as those described in Table 1.

CONCLUSION

The present study was designed to serve as the basis for future investigations into the effects of adaptive automation on pilot performance in an advanced tactical aircraft. As the first in a series of studies, the baseline study had a number of significant goals. A primary goal was to develop an appropriate research platform for conducting programmatic research into the human performance issues of adaptive automation. Consistent with this goal was the desire to study adaptive automation in the context of tasks representative of both traditional laboratory tasks found in the human performance literature and at the same time meaningful to the prediction of pilot performance in the tactical aircraft cockpit. Further, the baseline study was designed to allow several levels of task difficulty to be created on the tasks developed. Finally, the study was intended to demonstrate a methodology for examining and interpreting data under conditions in which multiple tasks and dependent measures are utilized.

The results of the study indicate that by and large the goals have been met. The Reconfigurable Cockpit (RC) has been chosen as the basis for conducting CAS research at NADC. It has proven to be a flexible and powerful research platform. The tasks currently implemented on the RC are representative of both critical tasks found in a tactical aircraft, and traditional laboratory tasks. A two-dimensional, first order pursuit tracking task served as a perceptual-motor task and was representative of the primary flight control task found in tactical aircraft. A Tactical Assessment Task (TAT) decision making task was developed from the laboratory binary classification task and was representative of a situational awareness task found in monitoring a tactical radar display. As a result of the baseline study, it was possible to assess the sensitivity of the dependent measures utilized, and the effectiveness of the independent manipulations in both complex task and single task performance. The present study also served as a vehicle for developing approaches and models which will allow for the interpretation of task interactions independent of effects due

to the introduction of automation. Further, aspects of these tasks may be used to demonstrate the effects of alternative adaptive automation systems on human performance. A methodology has been developed for interpreting the results, and generally meaningful results were obtained. The results from the baseline study demonstrated that the tasks will be sensitive and diagnostic for the study of automation when it is introduced to this environment.

After considerable work with the Reconfigurable Crew-station (RC), it was possible to collect tracking data, response time data and percent correct data with adequate resolution for the assessment of human performance in a complex task environment with resemblance to the operational task environment of a tactical aircraft. Two lines of future research have been defined based on the results of the baseline study. One line of research will use the tasks developed in this study in addition to a communication task which is currently being implemented on the RC. An additional line of research will develop a more realistic, higher fidelity derivative of the TAT and tracking task which is more appropriate for the use of skilled pilots and will be more representative of the tactical aircraft cockpit. The studies planned in the context of these two lines of research will incorporate aspects of current adaptive automation systems so that their impact on human performance may be empirically studied. The research will allow an examination of operator (pilot) strategies in performing a variety of complex tasks. Further, comparing across the two lines of research will permit the relative merits of predicting meaningful performance for the tactical aircraft pilot based on data collected in basic research. The ability to discuss these issues at the end of the ***Adaptive Function Allocation for Intelligent Cockpits*** program will represent a significant and meaningful contribution to the human performance literature and the application of adaptive automation technology to the tactical aircraft.

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APPENDIX 1:
Subject Protocol for Baseline Cockpit Automation Study.

TO: All prospective subjects 20 August 1990

FROM: J. G. Morrison Code 6021 x1443

SUBJECT: Adaptive Automation Pilot Study: Task description and subject briefing.

Thank you for agreeing to participate in the adaptive automation study. This experiment is one of a series of experiments being performed to assess how different types of automation which may be used in an aircraft cockpit affect pilot performance. Our goal is to try and bridge the gap between the findings of traditional laboratory experiments so that they impose the same kinds of demands as would be experienced by a Tactical Aircraft pilot. By doing this, we hope to learn how each of the tasks affects the ability to perform other tasks when they are being performed concurrently. The findings will then be used to help determine what tasks should be automated and when. This will ensure that the pilot's resources are allocated most effectively.

In this experiment you will perform two tasks: a tracking task and a tactical assessment task.

Tracking Task. You might want to think of this task as taking the place of flying an airplane. Your task is to fly the airplane so that you keep a set of crosshairs centered on the target airplane **at all times.**

- In effect, the crosshairs are painted on your windshield. If the target is above you, you must **pull** the stick back, thus pulling the nose of your airplane up to get closer to the target. If the target is below you, you must **push** the nose down by pushing the stick forward. To move to the left, push the stick to the left. To move the nose right, move the stick to the right. Remember, you should try to track the target as accurately as possible at all times.

- The wavy line you will see at the bottom of the screen represents the ground. It is there as a visual reference only - you do not need to worry about flying into it.

Tactical Assessment Task. This task requires that you monitor a series of targets which are moving across the screen and identify them as Enemy or Friendly when they come into range. In effect, the display is similar to what you'd see

monitoring a radar display of oncoming aircraft. You must identify the target that is near the outer semi-circle, or is between the inner and outer semi-circle.

- Only one target will need to be identified at a time. When the computer detects an eligible target you will see the word **TARGET** appear at the top of the screen. When you see the **TARGET** prompt, you should use your left index finger to push either the **CONfirm** or **DESignate** button as quickly and accurately as possible. **Friendly targets are CONfirmed**, while **hostile targets are DESignated.**

- When you are not identifying a target, it is very important that you keep your left index finger on the red dot (located on the left armrest). (This is because we are timing how long it takes you to press the correct button, and therefore for the time to mean anything, you must always start your hand from the same point.) Likewise, try not to start moving your hand before the **TARGET** prompt appears on the screen. You may monitor the progress of various symbols as they move across the screen, howeve- you should not begin your response until the word **TARGET** appears.

- NOTE: Not all the symbols will be seen before they cross into the area in which they must be identified. Some will "pop-up" between or near the two semi-circles.

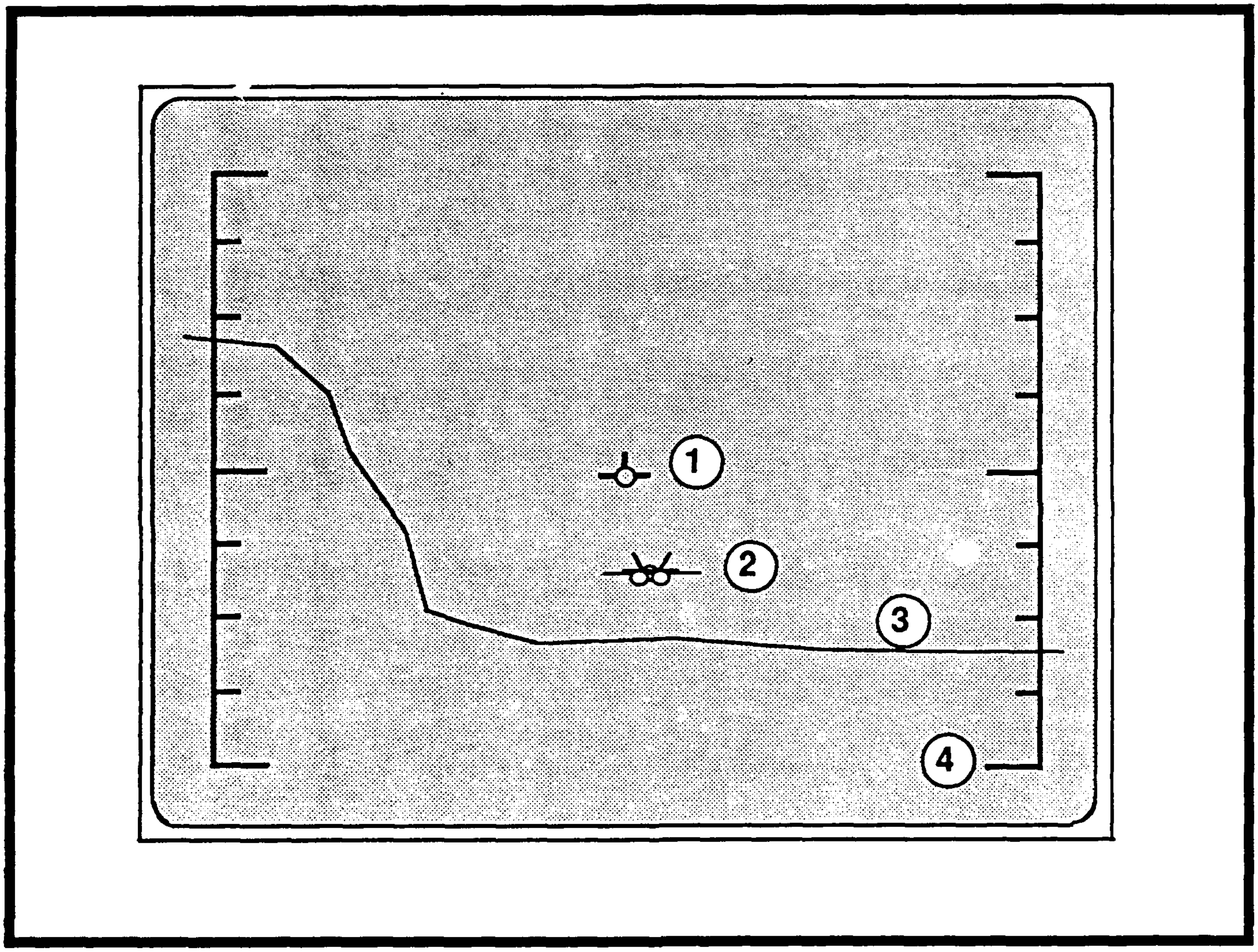
- You only have a few seconds in which to identify the targets, so you must pay attention to both the TAT and TRACKING tasks. Both are equally important.

- Please be careful not to touch any of the controls, pedals, or switches. We have not turned off most of the switches, etc. and as a result they will affect the way the tracking task works. There is a high probability that this will make the system crash outright. Even if the system doesn't crash, it would make your data worthless.

Enclosed is a list of the symbols being used for the Tactical Assessment task and their designations as friendly or hostile. Please study this list. Also enclosed is a practice test you may want to use to help learn the symbol codes. Please run through it. You will be asked to identify the symbols correctly before you begin each session.

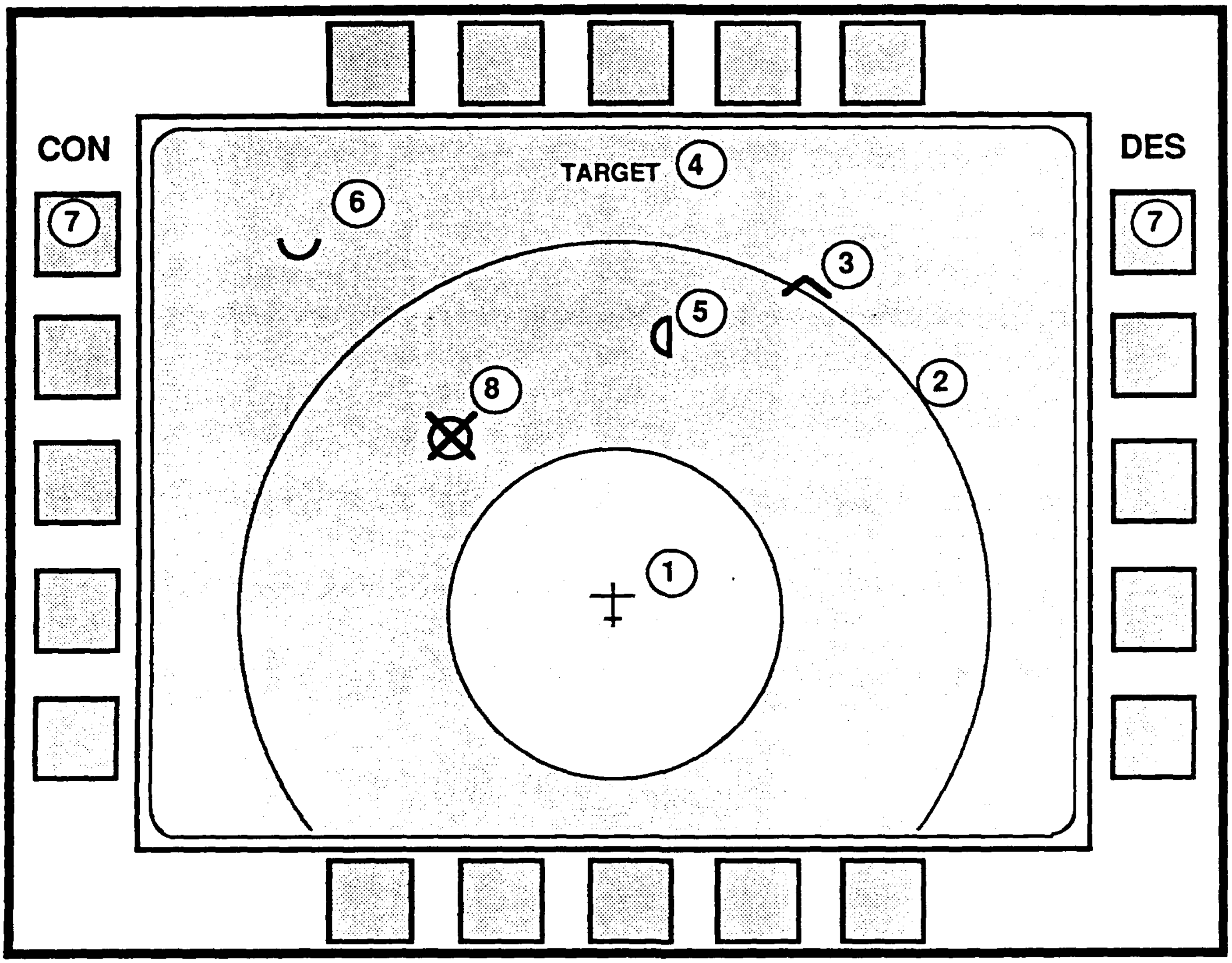
The experiment will require that you attend three sessions, each lasting approximately an hour. I ask that you try to arrange your schedule so that the sessions can be conducted at approximately the same time on two consecutive days. Again, thank you for your agreeing to participate in this study.

Tracking Task Display Format



1. Ownship bug (fixed to display)
2. Target (to be tracked)
3. Ground representation
4. Altitude scale

Tactical Assessment Task (TAT) Display Format



1. Ownship
2. Outer Range Ring (As targets approach they must be identified)
3. Target (to be identified)
4. `TARGET' Prompt- signals that a target must be identified
5. Target which has been correctly identified
6. Target which will need to be identified
7. Response buttons
8. Target which has been missed or incorrectly identified

Friendly	Hostile
∪	∨
∧	∩
<	(
○	◇
Confirm (CON) these Targets	**Designate (DES) these Targets**

Please use this short test to see how well you can identify each target symbol as being either Friendly or Hostile. Friendly symbols get confirmed; Hostile symbols get designated. Circle the corresponding letter for Confirmate (C) or Designate (D). You must be able to identify all symbols correctly. When you have finished, check your responses with the key on the preceeding page.

○ CD	< CD	◇ CD	∩ CD	(CD
< CD	◇ CD	∧ CD	(CD	∪ CD
∨ CD	∩ CD	< CD	∧ CD	◇ CD
(CD	∧ CD	(CD	< CD	○ CD
◇ CD	○ CD	∨ CD	◇ CD	∩ CD
∧ CD	(CD	◇ CD	○ CD	∪ CD
∪ CD	∪ CD	∩ CD	∪ CD	∨ CD
○ CD	∨ CD	∪ CD	∩ CD	< CD
◇ CD	(CD	○ CD	< CD	∩ CD
∧ CD	∪ CD	< CD	◇ CD	(CD
< CD	◇ CD	∨ CD	∩ CD	∧ CD
(CD	○ CD	(CD	∧ CD	< CD
∨ CD	∩ CD	◇ CD	○ CD	◇ CD
◇ CD	∪ CD	∧ CD	(CD	○ CD
∩ CD	∨ CD	∪ CD	○ CD	∪ CD
∪ CD	< CD	∨ CD	∪ CD	∩ CD

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